NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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A METHOD OF CALIBRATING AIRSPEED INSTALLATIONS ON AIRPLANES AT TRANSONIC AND SUPERSONIC SPEEDS BY USE OF TEMPERATURE MEASUREMENTS

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A METHOD OF CALIBRATING AIRSPEED INSTALLATIONS ON AIRPLANES AT TRANSONIC AND SUPERSONIC SPEEDS BY USE OF TEMPERATURE MEASUREMENTS

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SUMMARY

A method is described of calibrating airspeed installations on airplanes at transonic and supersonic speeds by use of instrumentation in the airplane only. The method consists in first making a survey of temperature, static pressure, and total pressure over the desired range of altitudes at speeds for which the airspeed calibration is known. The airplane is then flown at speeds for which the calibration is desired through the range of altitude surveyed, and the measurements of temperature, static pressure, and total pressure are repeated. The values of total pressure and indicated temperature at a given instant in the calibration run, together with the temperature recovery factor of the thermometer, define the relation between ambient temperature and static pressure at that instant. Comparison of this relation with that determined from the survey gives the value of free-stream static pressure at that instant. The static-pressure error is then obtained by subtracting the free-stream static pressure from the indicated static pressure. This method requires precise measurements of temperature. An accuracy in the calibration of 1.0 percent of Mach number near a Mach number of 1.0 corresponds to an accuracy in the measurement of temperature of $\frac{1}{2}^{\circ}$ F below and 2° F above the tropopause.

INTRODUCTION

The static-pressure source of a pitot-static airspeed installation on an airplane may be calibrated at low altitude and subsonic speeds, principally in level flight, by any one or more of several methods described in reference 1. For level-flight runs, dives, and maneuvers at high speeds and high altitudes, the radar method described in reference 2 may be used. In this method, the radar-phototheodolite tracking equipment is used to establish the geometric altitude of the airplane in surveys of atmospheric pressure made at speeds for which the airspeed calibration is known and in maneuvers under conditions for which the calibration is desired. Although this method of calibrating airspeed installations is very precise, its use is limited to agencies having

radar-phototheodolite equipment. Another method of calibrating airspeed installations at high speeds and high altitudes, which appears to have promise of wider use than the radar method, utilizes measurements of total pressure, static pressure, and temperature made in surveys at speeds where the calibration is known and in high-speed conditions where the calibration is desired. A description of this method together with a discussion of the various errors entering the calibration are presented in this paper.

SYMBOLS

p'	static pressure indicated by pitot-static installation
p	free-stream static or atmospheric pressure
p_T	free-stream total pressure for subsonic flow and total pressure behind normal shock for supersonic flow
M	Mach number
M'	indicated Mach number
M_l	local Mach number
T_m	measured temperature, absolute units
T	free-stream temperature, absolute units
T_l	local-stream temperature, absolute units
K_l	temperature recovery factor $\left(\frac{T_m - T_l}{0.2M_l^2T_l}\right)$
K	temperature recovery factor $\left(\frac{T_m - T}{0.2M^2T}\right)$

AIRPLANE EQUIPMENT

The airplane on which the static-pressure source of the pitot-static installation is calibrated should be equipped with a recording altimeter, an airspeed recorder, a thermometer having a high

temperature recovery factor, and a temperature recorder. The recording altimeter is used to record the static pressure measured by the static-pressure source. The airspeed recorder is used to record the impact pressure or the difference between total and static pressures measured by the pitot-static installation. The airspeed recorder and the recording altimeter should be the only instruments connected to the static-pressure source and should be located as near as possible to it in order to minimize the pressure lag of the recording system. The magnitude of the pressure lag may be determined by methods described in reference 1. If the lag is appreciable, corrections must be made to the measured static pressure. The thermometer should be properly shielded from radiation from the airplane and from the sun and should have a temperature recovery factor close to 1.0 in order to minimize any effects of local flow conditions. The thermometer should also have a low temperature lag. If the lag is appreciable, corrections to the recorded temperature must be made.

CALIBRATION PROCEDURE

One step of the calibration procedure consists in surveying the static pressure and temperature over an altitude range in which the calibration is to be performed. The survey may be made in level-flight runs, climbs, and/or descents by flying the airplane at a speed for which a calibration of the pitot-static installation exists or may be obtained by one of the methods described in reference 1. In the surveys, simultaneous measurements are made of impact pressure, static pressure, and temperature. The static-pressure and temperature are corrected to free-stream values by using the known calibrations for the static-pressure source and the thermometer. It appears desirable to repeat the surveys at various times during the calibration procedure in order to reduce the random errors and to obtain a check on the possible atmospheric changes if the calibrations are expected to take an appreciable time.

After the static-pressure survey, the airplane is flown through the region surveyed under conditions for which the calibration is desired, and simultaneous measurements are made of impact pressure, static pressure, and temperature.

EVALUATION OF DATA

The free-stream static pressure determined from the surveys can be expressed as a function of free-stream temperature, or

$$p = f(T) \tag{1}$$

For the calibration runs, free-stream static pressure may be obtained as a function of free-stream temperature by using the following relations: For $M \leqq 1.0$

$$\frac{p_T}{p} = (1 + 0.2M^2)^{3.5} \tag{2a}$$

For $M \geqq 1.0$

$$\frac{p_T}{p} = 1.2M^2\left(\frac{5.76M^2}{5.6M^2 - 0.8}\right)^{2.5} \tag{2b}$$

and

$$\frac{T_m}{T} = 1 + 0.2KM^2 \tag{3}$$

where p_T and T_m are measured in the calibration runs.

Combining equations (2) and (3) and eliminating M yields the following relations: For $M \leqq 1.0$

$$p = \frac{p_T}{\left[1 + \frac{1}{K}\left(\frac{T_m}{T} - 1\right)\right]^{3.5}} \tag{4a}$$

For $M \geqq 1.0$

$$p = \frac{p_T}{\frac{6}{K}\left(\frac{T_m}{T} - 1\right)}\left[\frac{\frac{28}{K}\left(\frac{T_m}{T} - 1\right) - 0.8}{\frac{28.8}{K}\left(\frac{T_m}{T} - 1\right)}\right]^{2.5} \tag{4b}$$

The simultaneous solution of equations (1) and (4) for given values of p_T and T_m yields the free-stream static pressure p which is then subtracted from the static pressure measured in the calibration run in order to determine the static-pressure error.

The most convenient solution of equations (1), (2), and (3) appears to be by a graphical method. In the graphical solution, the free-stream static pressure obtained in the surveys is plotted against free-stream temperature. Then, for given values of total pressure p_T and temperature T_m as measured at a given instant in the calibration

run, values of p and T are computed from equations (2) and (3), respectively, for several Mach numbers near the indicated Mach number. These values of p and T are then plotted on the graph showing the variation of free-stream static pressure with free-stream temperature as determined from the surveys. The intersection of the two curves determines the free-stream static pressure which, when subtracted from the static pressure obtained in the calibration run, gives the static-pressure error for that instant in the calibration run. This process is continued for other values of p_T and T_m obtained at other times during the calibration run until the static-pressure error for the entire calibration run is determined.

The method is further illustrated by a hypothetical calibration in tables 1 to 5 and in figures 1 and 2.

ACCURACY

The accuracy of the calibration depends primarily on the variation of atmospheric temperature with time and horizontal and vertical distance, the absolute value of the temperature recovery factor K of the thermometer, and the accuracy to which K is known. Since no comprehensive measurements have as yet been made to determine the variation of temperature with time and with horizontal distance at a given geometric altitude, the effect of these variations on the accuracy of a calibration cannot be estimated at the present. To minimize these effects, the calibration can be performed on days when there are practically no thermal currents at the desired altitudes or over areas where the thermal currents may be expected to be small. At altitudes above 35,000 feet, thermal currents are probably negligible. Because of the simplified calibration procedure, a number of survey and calibration runs may be made to fair out the random error.

Since equation (1) involves the variation of atmospheric pressure with temperature, the accuracy of the free-stream pressure determined from equations (1) and (4) would be expected to decrease if the variation of atmospheric pressure with temperature approached the adiabatic variation. An examination of weather records has shown that above an altitude of 20,000 feet, however, the variation of atmospheric pressure with temperature is seldom less than that for NACA standard atmosphere.

In the discussion of errors in the following paragraphs, the error in Mach number is considered rather than the error in static pressure since Mach number is of more immediate interest. In any case, a direct relation exists between error in Mach number and error in static pressure involving Mach number as a parameter.

The errors in Mach number due to errors in measuring temperature, in determining the value of K, and in measuring total and static pressures are derived in the appendix. The error in K due to local flow conditions is also derived in the appendix. The errors in Mach number due to an error of 1° F in temperature and an error of 0.01 in the value of K are plotted in figures 3 and 4, respectively. An error of 1° F in measured temperature at a Mach number of 0.8 corresponds to an error of about 0.02 in Mach number at altitudes below about 35,000 feet (altitudes with temperature gradient). Above 35,000 feet where practically no temperature gradient exists, the error in Mach number is about 1/3 the error for lower altitudes. The accuracy is also improved as the Mach number is increased.

An error of 0.01 in the value of K (for K in the neighborhood of unity) corresponds to an error of about 0.01 in Mach number at a Mach number of 0.8 (fig. 4). The error in Mach number above an altitude of about 35,000 feet is appreciably lower than below 35,000 feet.

In the appendix it may be seen that the accuracy of the calibration vanishes when the value of K lies between 0.66 and 0.31 for Mach numbers 0.4 to 1.8. Thermometers must therefore be chosen that have either a negligible recovery factor or a value of recovery factor approaching 1.0. A thermometer with a small or zero recovery factor would give appreciably improved accuracy when used at altitudes with a temperature gradient, but could not be used at all at altitudes with no temperature gradient. There may be some difficulty, however, in locating a thermometer with a low recovery factor on an airplane in order that the value of K would not be affected appreciably by local velocity. The error in recovery factor K due to local flow conditions is shown in figure 5. The error in K decreases as the value of K approaches 1.0 and, of course, vanishes at $K = 1.0$. On this basis, a thermometer having a value of K of 0.99 to 1.0 is recommended. An effort should be made in any case to locate the thermometer in a region where local velocity closely approaches free-stream velocity. When a thermometer with a low recovery factor is located in a region where the local velocity differs appreciably from free-stream velocity, the apparent error in K may be avoided, provided that the local Mach number is determined and equation (16) is used in place of equation (3).

The accuracy of an NACA recording altimeter and an airspeed recorder is ±1/4 percent of the full-scale reading. This accuracy would correspond to an accuracy of ±1 inch of water for the altimeter and ±0.38 inch of water for the airspeed recorder with a range of 150 inches of water. If the total pressure is obtained by adding the impact pressure to the static pressure, then the error in Mach number due to an error of 1 inch of water in static pressure at an altitude of 30,000 feet and a Mach number of 1.0 is 0.0034, according to equation (20) in the appendix.

Under corresponding conditions, the error in Mach number due to an error in impact pressure of 0.38 inch of water is 0.0027. The probable maximum error in Mach number for a single observation due to the errors in static pressure and impact pressure is $\sqrt{(0.0034)^2 + (0.0027)^2}$ or 0.004. The error in Mach number due to an error of 1.0 percent in total or free-stream static pressure is shown in figure 6.

CONCLUDING REMARKS

A method is described for calibrating the static-pressure source of a pitot-static airspeed installation on an airplane in maneuvers at transonic and supersonic speeds by use of only instrumentation in the airplane. The method consists in first making a survey of temperature, static pressure, and total pressure over the desired range of altitudes at speeds for which the calibration is known. The airplane is then flown at speeds for which the calibration is desired through the range of altitude surveyed, and the measurements of temperature, static pressure, and total pressure are repeated. The values of total pressure and indicated temperature at a given instant in the calibration run, together with the temperature recovery factor of the thermometer, define the relation between ambient temperature and static pressure at that instant. Comparison of this relation with that determined from the survey gives the value of free-stream static pressure at that instant. The static-pressure error is then obtained by subtracting the free-stream static pressure from the indicated static pressure.

Since the instruments required for the calibration are contained in the airplane, a calibration may always be readily obtained should the airplane enter a previously unexplored flight condition. No previous preparation for such a calibration is required beyond having the required instrumentation in the airplane.

The accuracy of the method depends primarily on the accuracy of the temperature measurements, the variation of temperature with altitude, and the variation of temperature with time and horizontal distance. The accuracy improves appreciably for altitudes above 35,000 feet where

there is no temperature gradient and also as the Mach number is increased. An accuracy in the calibration of 1.0 percent of Mach number near a Mach number of 1.0 corresponds to an accuracy in the measurement of temperature of $\frac{1}{2}^{\circ}$ F below and 2° F above the tropopause.

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APPENDIX

CALCULATION OF ERRORS

Error in Mach Number Due to Error in Measuring Total Temperature

Mach numbers equal to or less than 1.0.- From the surveys the free-stream static pressure can be expressed as

$$p = f(T)$$

This relation may be given more specifically relative to an arbitrary pressure p_1 and T_1 as

$$p = p_1 + \frac{dp}{dT}(T - T_1)$$

or

$$p = a + bT \tag{5}$$

If equations (2), (3), and (5) are combined, the relation for measured temperature is

$$T_m = \frac{1}{b}\left[\frac{p_T}{\left(1 + 0.2M^2\right)^{3.5}} - a\right](1 + 0.2KM^2) \tag{6}$$

Taking the derivative of T_m with respect to M and keeping p_T constant yields the following relation in differential form:

$$\Delta M = \frac{\Delta T_m}{0.4TM(1 + 0.2KM^2)\left[\frac{K}{1 + 0.2KM^2} - \frac{3.5}{1 + 0.2M^2}\,\frac{p}{\frac{dp}{dT}T}\right]} \tag{7}$$

For NACA standard atmosphere below 35,332 feet altitude

$$\frac{p}{\frac{dp}{dT}T} = 0.1903$$

and above 35,332 feet altitude

$$\frac{p}{\frac{dp}{dT}T} = 0$$

Equation (7), for altitudes less than 35,332 feet, reduces to

$$\Delta M = \frac{\Delta T_m}{0.4TM(1 + 0.2KM^2)\left(\frac{K}{1 + 0.2KM^2} - \frac{0.666}{1 + 0.2M^2}\right)} \tag{8a}$$

and, for altitudes above 35,332 feet, to

$$\Delta M = \frac{\Delta T_m}{0.4KTM} \tag{8b}$$

Mach numbers greater than 1.0.- Similarly, for Mach numbers greater than or equal to 1.0 and at altitudes of, or less than, 35,332 feet

$$\Delta M = \frac{\Delta T_m}{(1 + 0.2KM^2)\ \frac{T}{M}\left[0.1903\left(\frac{4}{5.6M^2 - 0.8} - 2\right) + \frac{0.4KM^2}{1 + 0.2KM^2}\right]} \tag{9a}$$

and for altitudes above 35,332 feet

$$\Delta M = \frac{\Delta T_m}{0.4KMT} \tag{9b}$$

Error in Mach Number Due to Error in Recovery Factor K

Mach numbers equal to or less than 1.0.- Keeping p_T and T_m constant in equation (6) and differentiating gives the following relation for error in Mach number due to an error in the recovery factor K

$$\frac{\Delta M}{M} = \frac{\Delta K/K}{\frac{7}{K}\ \frac{p}{bT}\ \frac{1 + 0.2KM^2}{1 + 0.2M^2} - 2} \tag{10}$$

From NACA standard atmosphere at or below 35,332 feet altitude equation (10) becomes

$$\frac{\Delta M}{M} = \frac{\Delta K/K}{\frac{1.332}{K}\ \frac{1 + 0.2KM^2}{1 + 0.2M^2} - 2} \tag{11a}$$

Above an altitude of 35,332 feet

$$\frac{\Delta M}{M} = -\frac{1}{2}\frac{\Delta K}{K} \tag{11b}$$

Mach number greater than 1.0.- Similarly for Mach numbers greater than 1.0, the error in Mach number due to an error in recovery factor K is

$$\frac{\Delta M}{M} = -\frac{\Delta K/K}{5\frac{\left(1 + 0.2KM^2\right)}{KM^2}\left(\frac{4}{5.6M^2 - 0.8} - 2\right)\frac{p}{bT} + 2} \tag{12a}$$

For altitudes at and below 35,332 feet

$$\frac{\Delta M}{M} = -\frac{\Delta K/K}{0.952\frac{1 + 0.2KM^2}{KM^2}\left(\frac{4}{5.6M^2 - 0.8} - 2\right) + 2} \tag{12b}$$

and for altitudes above 35,332 feet

$$\frac{\Delta M}{M} = -\frac{1}{2}\frac{\Delta K}{K}$$

Effect of Temperature Recovery Factor on Accuracy of Calibration

From equations (8a), (9a), (11a), and (12a), the accuracy may be seen to vanish for $M \leqq 1.0$ when

$$\frac{K}{1 + 0.2KM^2} - \frac{0.666}{1 + 0.2M^2} = 0$$

or

$$K = \frac{0.666}{1 + 0.0668M^2} \tag{13a}$$

and for $M \geqq 1.0$ when

$$\frac{0.4KM^2}{1 + 0.2KM^2} + 0.1903\left(\frac{4}{5.6M - 0.8} - 2\right) = 0$$

or

$$K = \frac{-0.1903\left(\frac{4}{5.6M^2 - 0.8} - 2\right)}{0.2M^2\left[2 + 0.1903\left(\frac{4}{5.6M^2 - 0.8} - 2\right)\right]} \tag{13b}$$

The values of K at which the accuracy vanishes are tabulated as follows:

M	K
0.4	0.66
.6	.65
.8	.64
1.0	.62
1.4	.46
1.8	.31

Error in Recovery Factor K Due to Location of

Thermometer in Local Flow

The error in K due to the location of the thermometer in a region of local flow may be obtained by using the following relations:

$$T_l = \frac{T_m}{1 + 0.2K_l M_l^2} \tag{14}$$

and

$$T_l = T\,\frac{1 + 0.2M^2}{1 + 0.2M_l^2} \tag{15}$$

where K_l is the recovery factor based on local Mach number M_l. Elimination of T_l from equations (14) and (15) results in the expression

$$T = \frac{T_m}{1 + 0.2M^2}\,\frac{1 + 0.2M_l^2}{1 + 0.2K_l M_l^2} \tag{16}$$

Combining equation (16) with equation (3) by eliminating T and then solving for K gives the following relation:

$$K = \frac{1}{0.2M^2}\left[\frac{1 + 0.2M^2}{1 + 0.2M_l{}^2}\left(1 + 0.2K_lM_l{}^2\right) - 1\right] \tag{17}$$

The error in K is then

$$\Delta K = K_l - K = K_l - \frac{1}{0.2M^2}\left[\frac{1 + 0.2M^2}{1 + 0.2M_l{}^2}\left(1 + 0.2K_lM_l{}^2\right) - 1\right] \tag{18}$$

Error in Mach Number Due to an Error in Measuring

Static Pressure and Total Pressure

Differentiation of equations (2) for $M \leqq 1.0$ yields

$$\Delta M = -\frac{1 + 0.2M^2}{1.4M}\frac{\Delta p}{p} \tag{19a}$$

and

$$\Delta M = \frac{1 + 0.2M^2}{1.4M}\frac{\Delta p_T}{p_T} \tag{19b}$$

For combined errors in static and total pressure

$$\Delta M = \frac{1 + 0.2M^2}{1.4M}\left(\frac{\Delta p_T}{p_T} - \frac{\Delta p}{p}\right) \tag{20}$$

Similarly for $M \geqq 1.0$

$$\Delta M = -\frac{M}{-\frac{4.0}{5.6M^2 - 0.8} + 2}\frac{\Delta p}{p} \tag{21a}$$

and

$$\Delta M = \frac{M}{-\frac{4.0}{5.6M^2 - 0.8} + 2} \frac{\Delta p_T}{p_T} \tag{21b}$$

For combined errors in static and total pressures

$$\Delta M = \frac{M}{-\frac{4.0}{5.6M^2 - 0.8} + 2} \left(\frac{\Delta p_T}{p_T} - \frac{\Delta p}{p}\right) \tag{22}$$

REFERENCES

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TABLE 1.- VARIATION OF ATMOSPHERIC PRESSURE WITH TEMPERATURE FOR HYPOTHETICAL SURVEY

[All pressure given in inches of water and temperatures in °F abs.]

p_T (a)	p' (a)	T_m (a)	q_c' (a)	$p' - p$ (b)	p (c)	p_T/p	M	$1 + 0.198M^2$ (d)	T
143.6	124.0	431.1	19.6	0.4	123.6	1.162	0.468	1.0434	413.2
140.9	121.2	429.7	19.7	.4	120.8	1.166	.474	1.0445	411.4
138.1	118.5	428.1	19.6	.4	118.1	1.169	.478	1.0452	409.6
135.6	115.8	426.9	19.8	.4	115.4	1.175	.486	1.0468	407.8
132.9	113.2	425.3	19.7	.4	112.8	1.178	.489	1.0473	406.1
130.2	110.6	423.7	19.6	.4	110.2	1.181	.493	1.0481	404.3
125.1	105.6	421.0	19.5	.4	105.2	1.189	.504	1.0507	400.7
120.4	100.8	418.1	19.6	.4	100.4	1.199	.516	1.0527	397.2
115.8	96.1	415.4	19.7	.4	95.7	1.210	.529	1.0554	393.6
111.3	91.7	415.0	19.6	.4	91.3	1.219	.539	1.0575	392.4
107.0	87.4	416.1	19.6	.4	87.0	1.230	.552	1.0603	392.4
103.1	83.3	417.4	19.8	.4	82.9	1.244	.567	1.0637	392.4
99.1	79.5	418.3	19.6	.4	79.1	1.253	.577	1.0659	392.4

[a]Obtained from measurements in survey.

[b]Obtained by using a static-pressure error $\frac{p' - p}{q_c} = 0.02$. This error would be known from previous lower-speed calibrations.

[c]Static pressure is plotted aginst temperature in fig. 1 and is labeled "Survey."

[d] $\frac{T_m}{T} = 1 + 0.2KM^2$ where K, the temperature recovery factor, is taken as 0.99 for the example.

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TABLE 2.- TOTAL PRESSURES, STATIC PRESSURES, AND TEMPERATURES FOR HYPOTHETICAL CALIBRATION DIVE

[All pressures given in inches of water and temperatures in °F abs.]

p_T	p'	T_m	$\frac{p_T}{p'}$	M'
121.9	81.5	442.1	1.495	0.781
141.8	90.7	448.5	1.563	.825
162.2	99.3	456.6	1.633	.867
183.6	107.9	470.2	1.702	.906
211.0	118.9	486.3	1.775	.944
211.0	113.0	486.3	1.867	.988
231.7	116.6	496.8	1.987	1.041
259.1	122.8	510.5	2.110	1.091

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TABLE 3.- VALUES OF T/T_m FOR VARIOUS VALUES OF p/p_T

COMPUTED BY USING EQUATIONS (2) AND (3)

[Table made up for convenience of computing p and T; all pressures given in inches of water and temperatures in $^{\circ}$F abs.]

p/p_T	p_T/p	M	$1 + 0.198M^2$	T/T_m
0.40	2.5000	1.231	1.3000	0.7692
.41	2.4390	1.211	1.2904	.7750
.42	2.3809	1.191	1.2809	.7807
.43	2.3256	1.171	1.2715	.7865
.44	2.2727	1.152	1.2628	.7919
.45	2.2222	1.134	1.2546	.7971
.46	2.1739	1.116	1.2466	.8022
.47	2.1277	1.098	1.2387	.8073
.48	2.0833	1.080	1.2309	.8124
.49	2.0408	1.063	1.2239	.8170
.50	2.0000	1.046	1.2168	.8218
.51	1.9608	1.030	1.2100	.8264
.52	1.9231	1.013	1.2032	.8311
.53	1.8868	.997	1.1968	.8356
.54	1.8519	.981	1.1905	.8400
.55	1.8182	.965	1.1844	.8443
.56	1.7857	.949	1.1783	.8487
.57	1.7544	.933	1.1724	.8530
.58	1.7241	.917	1.1665	.8573
.59	1.6949	.902	1.1611	.8612
.60	1.6667	.887	1.1558	.8652
.61	1.6393	.871	1.1502	.8694
.62	1.6129	.855	1.1447	.8736
.63	1.5873	.840	1.1398	.8773
.64	1.5625	.824	1.1344	.8815
.65	1.5385	.809	1.1296	.8853
.66	1.5151	.794	1.1248	.8890
.67	1.4925	.778	1.1198	.8930
.68	1.4706	.763	1.1153	.8966

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TABLE 4.- COMPUTATION OF p AND T BY USING MEASURED VALUES OF p_T AND T_m AND TABLE 2

p_T	T_m	p/p_T	T/T_m	p (a)	T
121.9	442.1	0.650 .660 .670	0.8853 .8890 .8930	79.2 80.5 81.7	391.4 393.0 394.8
141.8	448.5	.610 .620 .630	.8694 .8736 .8773	86.5 87.9 89.3	389.9 391.8 393.5
162.2	456.6	.580 .590 .600	.8573 .8612 .8652	94.1 95.7 97.3	391.4 393.2 395.0
183.6	470.2	.550 .560 .570	.8443 .8487 .8530	101.0 102.8 104.6	397.0 399.1 401.1
211.0	486.3	.510 .520 .530	.8264 .8311 .8356	107.6 109.7 111.8	401.9 404.2 406.4
231.7	496.8	.490 .500 .510	.8170 .8218 .8264	113.5 115.8 118.2	405.9 408.3 410.6
259.1	510.5	.460 .470 .480	.8022 .8073 .8124	119.2 121.8 124.4	409.5 412.1 414.7

[a]Static pressure is plotted against temperature in fig. 1. Intersection of these curves with survey curve determines the free-stream static pressure for the particular values of p_T and T_m in the calibration run.

TABLE 5.- COMPUTATION OF ERRORS IN STATIC PRESSURE

AND MACH NUMBER FOR THE HYPOTHETICAL CALIBRATION

[All pressures in inches of water.]

p_T (a)	p' (a)	p (b)	$p' - p$	$\frac{p' - p}{p}$	p_T/p	M	M' (a)	ΔM
121.9	81.5	80.0	1.5	0.019	1.524	0.800	0.781	-0.019
141.8	90.7	88.4	2.3	.026	1.604	.850	.825	-.025
162.2	99.3	95.7	3.6	.038	1.695	.902	.867	-.035
183.6	107.9	102.7	5.2	.051	1.788	.950	.906	-.044
211.0	118.9	109.0	9.9	.091	1.936	1.019	.944	-.075
211.0	113.0	109.0	4.0	.037	1.936	1.019	.988	-.031
231.7	116.6	115.2	1.1	.010	2.011	1.051	1.041	-.010
259.1	122.8	121.5	1.3	.011	2.133	1.100	1.091	-.009

NACA

[a]From table 2.

[b]Taken from intersection of curves in fig. 1.

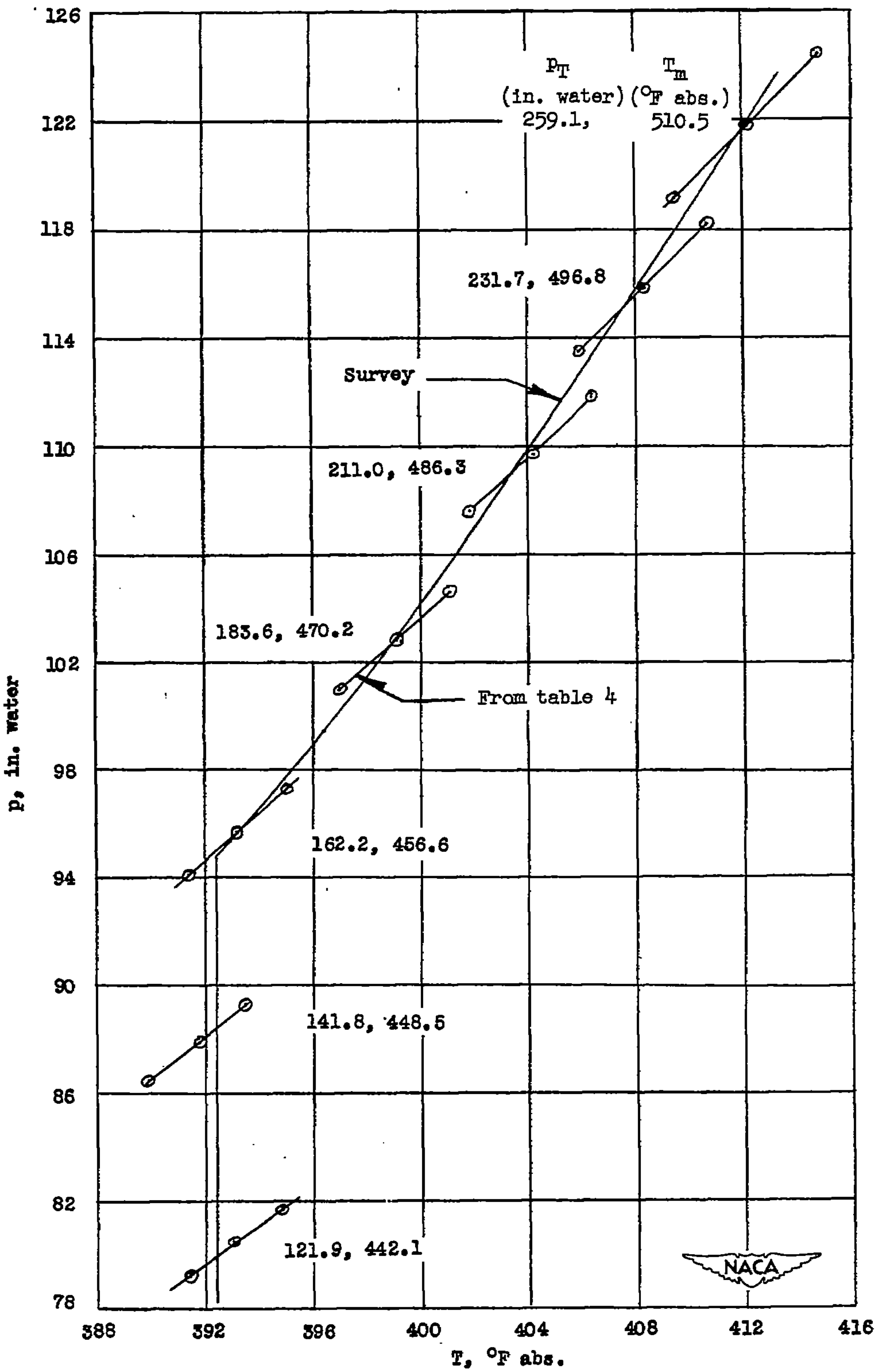

Figure 1.- Determination of free-stream static pressure from the survey and dive for a hypothetical calibration.

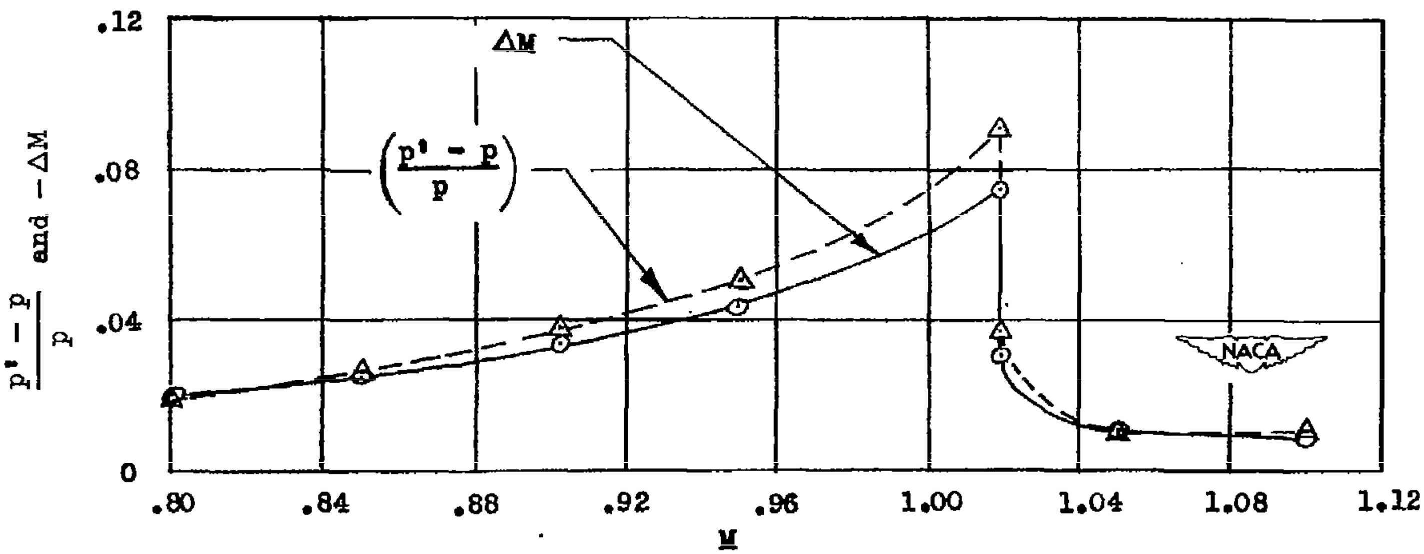

Figure 2.- Error in static pressure and Mach number for the hypothetical calibration.

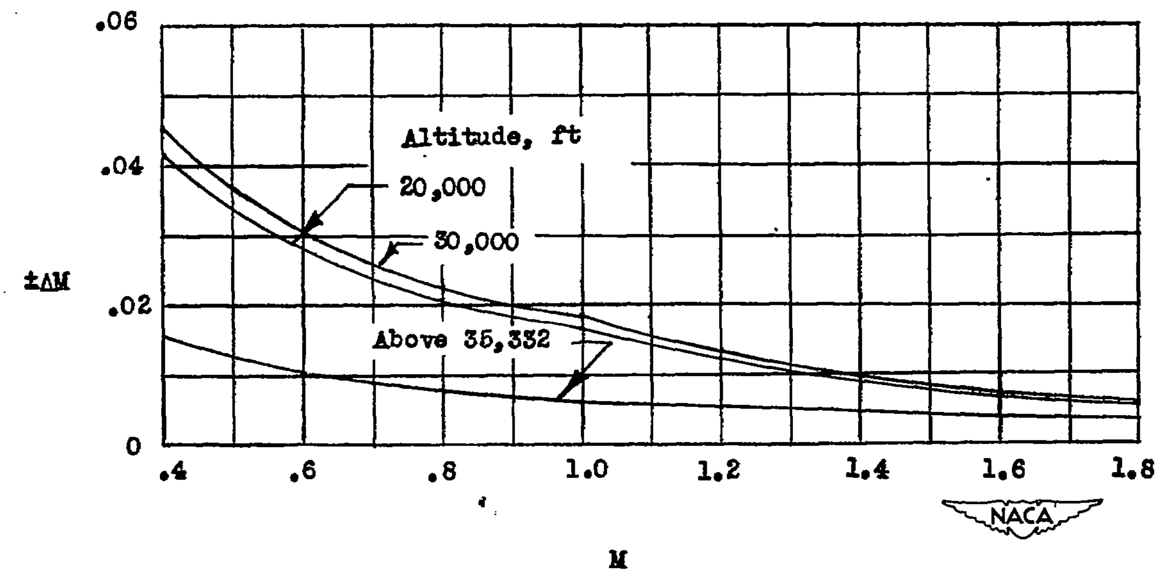

Figure 3.- Error in Mach number for an error of ±1° F in measured temperature K = 1.0. NACA standard atmosphere.

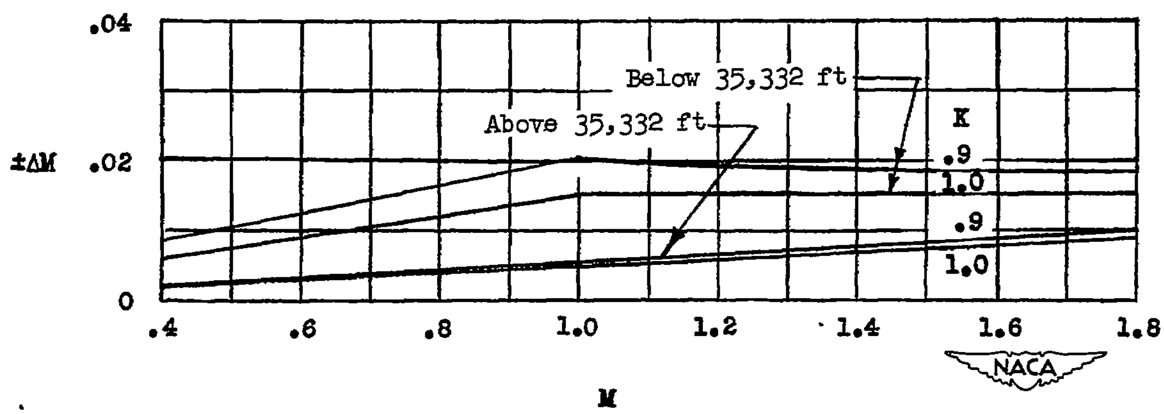

Figure 4.- Error in Mach number for an error in K of ∓0.01. NACA standard atmosphere.

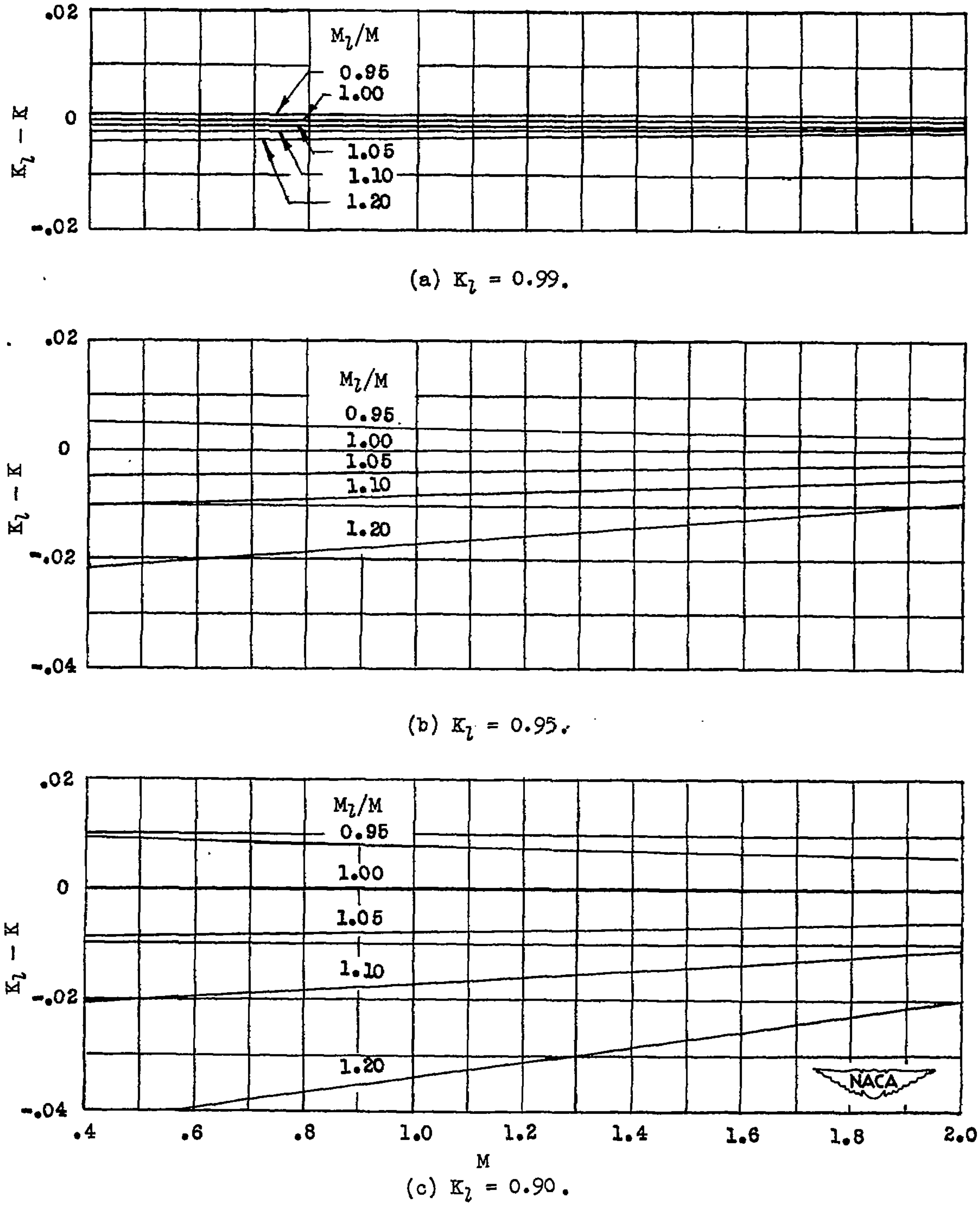

Figure 5.- Apparent error in recovery factor due to local flow conditions.

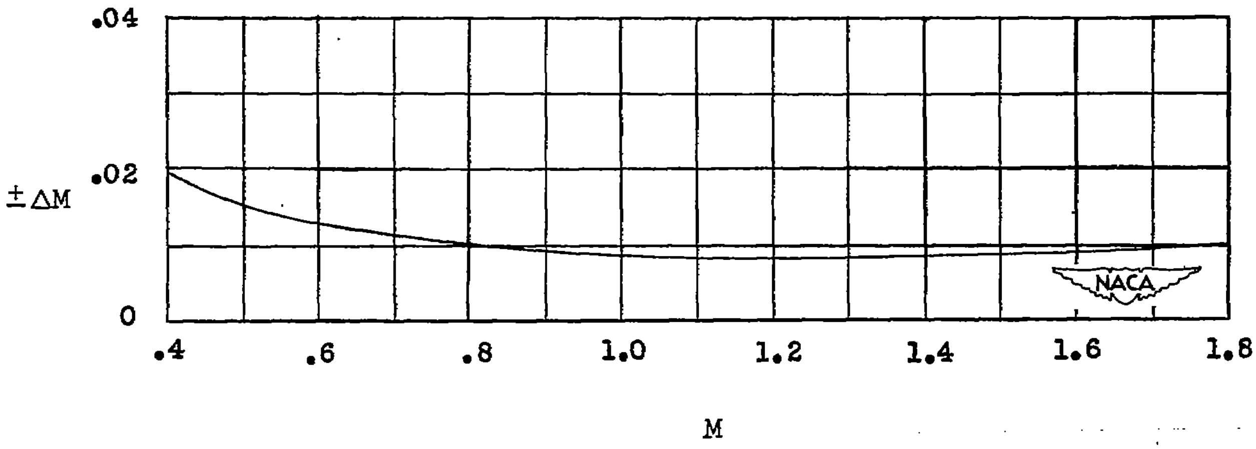

Figure 6.- Error in Mach number due to an error of ∓1.0 percent in static pressure or ±1.0 percent in total pressure.